Chapter 1

Overview

Communication networks are arrangements of hardware and software that enable the transfer of bit streams or bit files. This course focuses on a specific collection of networks called the Internet. In the next section, we briefly review how Internet is organized.

1.1 How Internet Works

The Internet uses packet switching. We explain the unreliable packet delivery service that the Internet Protocol provides and how a reliable service is built on top of that service. We then describe the point-to-point links that connect devices. We illustrate these ideas with a set of Ethernets connected by routers. We conclude the section with a few words about the Domain Name System.

1.1.1 Packet Switching

In packet switched networks, the source assembles the bits it wants to send into packets. A packet is a group of source bits together with some control information. The control information in a packet includes the source and destination addresses, a sequence number, and error detection bits. The packets travel across digital links attached to routers. Each router maintains a routing table that identifies the outgoing port that corresponds to the destination address of the packet.
1.1.2 Addressing

The addresses are organized based on the topology of the network, in a way similar to the telephone numbers. This geographical structure of the addresses greatly simplifies the routing tables that the routers must maintain. All the destination addresses that start with the same group of bits are attached to the same router port and the table only needs one entry for that group of addresses.

1.1.3 Internet Protocol

With this arrangement of addresses and routing tables, the network can deliver a packet from any source to any destination. This packet delivery service, called the Internet Protocol, is said to be best effort because it provides no guarantee on delays or delivery rate.

It may happen that a router receives packets faster than it can send them out. If the situation persists, the router may run out of available memory to store incoming packets and may have to discard some of them. It may also happen occasionally that a packet is corrupted as it propagates on a link between routers. Accordingly, the best effort delivery service is not fully reliable.

It may be necessary for a router to decompose a packet into smaller fragments to respect the maximum transfer size of the outgoing link. The packet has control information that enables the reassembly of fragments by the ultimate destination. In addition, the packet contains an indication of the number of routers that it can still go through. Routers use this indication, called the time-to-live of the packet, to discard packets that may happen to loop in the network. Packets also contain an indication of the differentiated service that they should receive. For instance, a value of that indicator may specify that the router should forward the packet before packets with a different value. Finally, the router only checks an error detection field that protects the control information of the packet, but not the data in the packet. A router discards a packet whose control information is corrupted, but forwards packets with corrupted data and correct control information. Only the destination checks the correctness of the data.

1.1.4 Transmission Control Protocol

A reliable delivery service, called the Transmission Control Protocol, is built on top of the best effort packet delivery that the Internet Protocol provides and it works as follows. When it gets a correct packet, as determined from the error detection bits, the destination sends an acknowledgement back to the source with the corresponding sequence number. If acknowledgements
fail to come back within a given time, the source suspects that some routers were congested and
had to discard packets. When this occurs, the source retransmits the unacknowledged packet
and slows down the rate at which it sends packets into the network to reduce the congestion.
When acknowledgements come back as expected, the source increases its packet transmission
rate.

1.1.5 Framing

There are two types of links in the Internet: point-to-point links and shared links. A point-
to-point link transports bits by using a specific encoding and modulation scheme. To send a
packet, the transmitter adds specific control bits to identify the start and end of the packet in
the bit stream. The transmitter may also add error detection bits. We say that the transmitter
sends a frame. That frame is a container for the packet.

1.1.6 Shared Links

A shared link attaches a number of transmitters and receivers. These devices are distinguished
by a unique link address. When sending a packet on a shared link, the source adds the link
source address and the link destination address and then frames the augmented packet. For
instance, assume that the packet is $PACKET = [S|D|data|ED]$ where $S$ is the source address,
$D$ the destination address, $data$ are the bits being sent, and $ED$ are the error detection bits.
If this packet goes across a shared link with link source address $x$ and link destination address
$y$, then the frame will have the structure $[x|y|PACKET|ed]$ where $ed$ designates the error
detection bits of the link.

1.1.7 Ethernet

A widely used shared link technology is Ethernet. A typical Ethernet consists of a number
of copper or fiber links attached to Ethernet switches, computers, routers, and other devices.
Each Ethernet switch maintains a table that identifies the port to which each of a set of link
addresses are attached. In contrast with the Internet addresses, the Ethernet addresses have
no geographical structure. We say that Ethernet uses a flat addressing space. Accordingly,
each Ethernet switch table needs one entry for every device attached to this network. Such a
flat addressing scheme limits the number of devices that can be on the same Ethernet.
1.1.8 Representative Network

Figure 1 illustrates a representative network. The figure shows three Ethernets $E_1, E_2, E_3$ attached to a router $R_1$. That router is attached to two other routers $R_2$ and $R_3$. Router $R_3$ is attached to the rest of the Internet. The figure also shows three computers with Internet addresses $N_1.3, N_1.7$, and $N_6.5$. All the devices attached to $E_1$ have Internet address of the form $N_1.x$. The link address (also called Ethernet address) of the computer with Internet address $N_1.3$ is $a$. The figure also shows the other link addresses. To send a packet $PACKET_1 = [N_1.3|N_1.7|data|ED]$ to $N_1.7$, computer $N_1.3$ first determines whether $N_1.7$ is on the same Ethernet as it is. To do this, $N_1.3$ compares the prefix $N_1$ of its Internet address with the prefix $N_1$ of the address $N_1.7$. (The length of the prefix is specified for each device.) Since these prefixes are equal, the two computers are on the same Ethernet. Accordingly, $N_1.3$ frames the packet into an $E_1$ frame as $[a||b|PACKET_1|ed]$ and sends the frame. $E_1$ delivers that frame to $b$ which extracts the packet $PACKET_1$. To learn the link address $b$ that corresponds to $N_1.7$, computer $N_1.3$ uses the address resolution protocol. Essentially, $N_1.3$ broadcasts a request on $E_1$ that asks for $N_1.7$ to reply. All the devices on $E_1$ get this request and $N_1.7$ replies. The need for broadcasting such requests is another reason why the number of devices on an Ethernet must be limited.

When sending a packet $PACKET_2 = [N_1.3|N_6.5|data|ED]$ to $N_6.5$, computer $N_1.3$ finds out that the destination is not on $E_1$. The rule is then for $N_1.3$ to send the packet to the “default router” $R_1$ to exit $E_1$. Computer $N_1.3$ sends the frame $[a||c|PACKET_2|ed]$ to the router $R_1$ that then extracts $PACKET_2$. $R_1$ searches its routing table to determine the port to which it should send $PACKET_2$. That routing table has an entry for $N_6$ which points to port 3. $R_1$ then sends $PACKET_2$ on that port, with the framing suitable for that point-to-point link. Router $R_2$ follows a similar procedure and sends $PACKET_2$ to its port 2.

1.1.9 Domain Name System

Computers are identified by names that are easier to remember than Internet addresses. For instance, you may want to browse CNN.com. A distributed directory service, called the Domain Name System, provides the Internet address of a computer with a given name.